



## Geologic Characteristics of Deep Reservoirs in Kelasu Structural Belt, Kuche Depression, Tarim Basin, NW China

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### Background

Kuqa Depression is a principal production area in northern Tarim Basin and has favorable conditions for giant gas accumulation. Large hydrocarbon traps were formed by large-scale imbricated thrust structures. Excellent source rocks and large amount of gas charge in late stage provide sufficient hydrocarbon sources. Deep massive sandstone acts as good reservoirs for this giant gas accumulation. Thick gypsum beds acts as good capping rocks. Kelasu Structural Belt is one of the uplifts in northern Kuqa Depression and was formed by late-stage Himalayan Tectonic Movement. Its structural development is controlled by regional thrusting faults and characterized by significant zonation (4 structural belts) in SN direction, segmentation (5 segments) in EW direction, all of which are identified by different regional faults and structural styles; and vertical layering. Almost 20 bcm/a gas production comes from three giant gas fields, namely, Kela-2, Keshen-2 and Dabei, all of which are located in Kelasu Structural Belt (Fig.1).

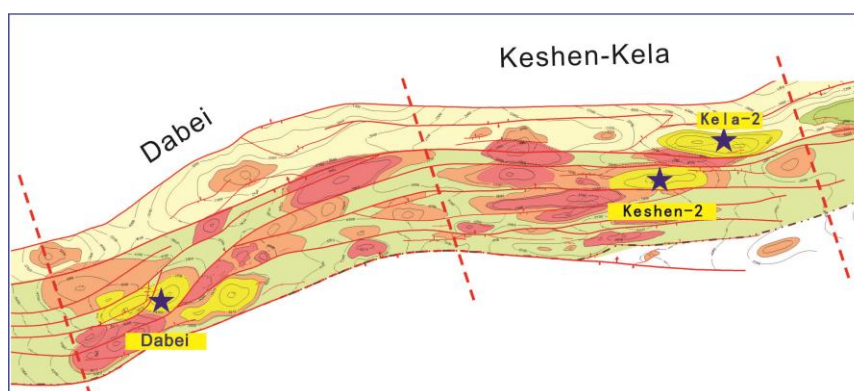
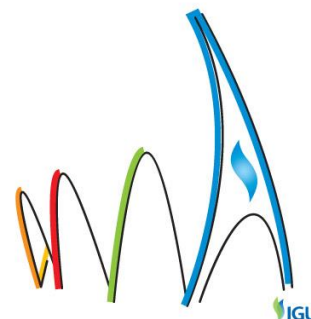


Fig.1 Kelasu Structural Belt and Location of Gas Fields



#### Aim

High production capacities are anticipated in three gas fields and different characteristics with the details as follows. Kela-2 Gas Field, defined as ultra-high pressure gas reservoir (pressure coefficient 1.95-2.20) in NE Kelasu Structural Belt, has good reservoir quality and excellent connectivity by faults in relatively shallow burial depth; Keshen-2 Gas Field, defined as high pressure gas reservoir (pressure coefficient 1.62-1.81) in eastern Kelasu Structural Belt, has poor reservoir quality and good connectivity by fractures in deep burial depth of about 6,000-7,500m; and Dabei Gas Field, defined as high pressure reservoir (pressure coefficient 1.54-1.72), is a multi-faulted-block reservoir with poor reservoir quality and fracture development in the burial depth of about 5,000-7,000m. Based on the detailed study on different reservoir types, the characteristics and controlling factors of high-productivity reservoirs have been identified in Kelasu Structural Belt.

#### Methods

The generality and specific characteristics of reservoir have been studied by the analogy in three gas fields. Researches focus on the sedimentary facies, petrology, geophysical properties, barriers, interlayers, fractures, faults, connectivity. Outcrop research, petrophysical experiments, massive statistics work and analogue research have been carried out. Geological model and discrete fractures network model were built to predict the structures and development of fractures and inner faults.

#### 1 Regional structure

Kuqa Depression in the Tarim Basin is a foreland basin in the southern Tianshan Mountains structural belt. The depression borders the southern Tianshan Mountains structural belt on the north and Tabei uplift on the south with an east-west length of 550km and a south-north width of 30-80km as well as an area of 28,515km<sup>2</sup>. Four structural belts and three sags composed the depression. From the north to south, the four structural belts are the northern monocline belt, Kelasu structural belt, Qiulitage structural belt and the frontal uplift belt. From the west to the east, the three sags are Wushi sag, Baicheng sag and Yangxia Sag<sup>[1]</sup>.

The Kelasu structural belt is one of the uplifts in the north of the Kuqa Depression and formed in the late period of the Himalayan movement<sup>[2-4]</sup>. Previous works on the structural style elaborated the evolutionary history of Kelasu structural belt<sup>[4-5]</sup> (Fig.2). Formation and evolution of this structural belt are mainly under the control of the Dawanqibei-Kelasu faulted belt<sup>[1]</sup>. The fault system was composed of a series of north dipping thrust faults. These faults occurred in the Jurassic, Cretaceous and vanished in the salt bed in the KM formation of Early Tertiary. The above-salt structure is a kind of propagation fold formed by sliding along the Upper Tertiary sliding-off fault, which inclines generally towards the north. The structure

under the salt bed is a complicated anticlinal belt composed of overlapping fault bend folds <sup>[6]</sup>. The upper part formed the Kela-2 anticline and deeper part shaped the Keshen-2 trap (Fig.3).

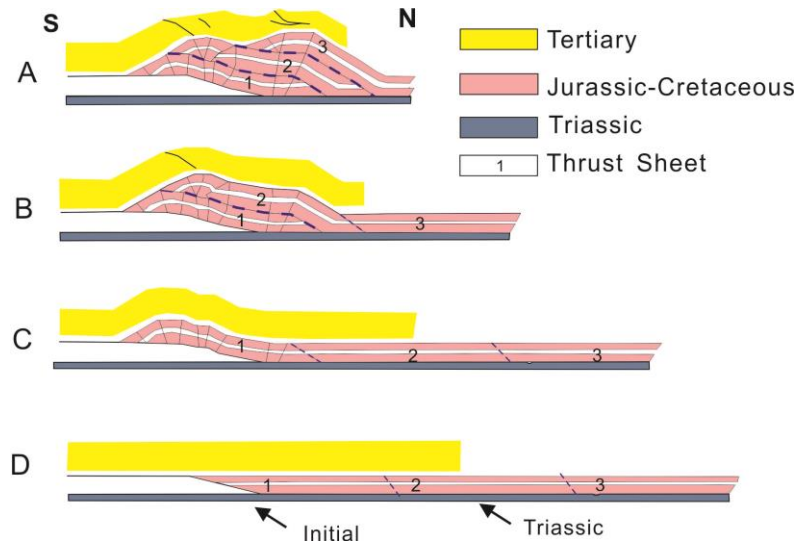


Fig.2 Tectonic evolution of Kelasu Structural Belt

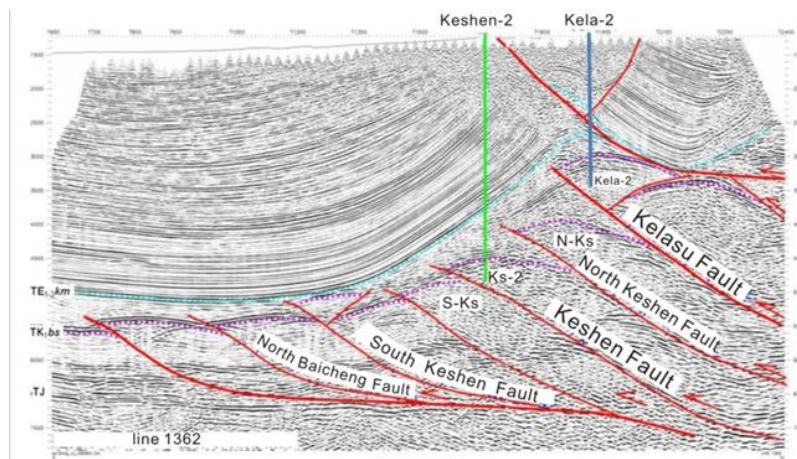


Fig.3 Fault system in Kelasu structural belt

## 2 Strata

Middle-Upper Triassic to Middle-Lower Jurassic consists of lake-swamp coal measures deposited under humid paleoclimate and proved as effective gas source <sup>[7-9]</sup>.

The gas-bearing layer is Bashijiqike formation in the Lower Cretaceous and mainly composed of a combination alluvial-fluvial deposition in a relatively dry and closed environment<sup>[10]</sup>. It can be divided into three lithological members. The first member experienced erosion in different level which had correlation with the depositional background of Kulasu tectonic zone. The first and the second member have the similar lithology – medium sandstone interbedded with a small amount of mudstone and pelitic siltstone. The second member contained more pure muddy interlayers than the first member. The lithology of the third member is siltstone interbedded with gompfolite.

The Paleogene and Neogene consist of sedimentary combination of briny lagoon deposited under dry paleoclimate. Approximately more than 1000m thickness KM strata overlies on the gas-bearing layer. From the upper part to the lower part, the KM strata can be divided into five lithological members in detail: mudstone, gypsiferous salt rock, dolomite, gypsiferous marl and glutenite (Tab.1). The giant thickness gypsiferous salt rock and gypsiferous marl are a set of high quality regional seal rocks which is the key factor for the oil and gas abundant in Kuqa front land thrust belt<sup>[11-12]</sup>.

Tab.1 Stratigraphy of Kulasu structural belt

System	Strata			Code
	Strata	Formation	Member	
Early Tertiary	Oligocene	Suweiyi		E <sub>2-3</sub> S
	Palaeocene-Eocene	KM	Mudstone	E <sub>1-2</sub> KM <sup>1</sup>
			Gypsiferous Salt Rock	E <sub>1-2</sub> KM <sup>2</sup>
			Dolomite	E <sub>1-2</sub> KM <sup>3</sup>
			Gypsiferous Marl	E <sub>1-2</sub> KM <sup>4</sup>
Cretaceous	Lower Cretaceous	Bashijiqike	Glutenite	E <sub>1-2</sub> KM <sup>5</sup>
			First	K <sub>1</sub> bs <sup>1</sup>
			Second	K <sub>1</sub> bs <sup>2</sup>
			Third	K <sub>1</sub> bs <sup>3</sup>

### 3 Depositional background and sedimentary facies

After Mesozoic, Kuqa area experienced intense thrust-motion from the northern Tianshan orogen and generated foreland basin in the south. The palaeogeographical framework showed mountain in the north and basin in the south which controlled the development of sedimentary facies. In Cretaceous, Tianshan orogen had uplifted and Kuqa area began to form depression so that the geography controlled the direction of the fluid flow. Many exits of provenance occurred in the Tianshan orogen and the clastic sediments deposited in relative fast speed in the Kuqa depression. From the north to the south, the sedimentary facies is alluvial fan, fan delta or braided delta and shore, respectively<sup>[12-13]</sup>. Alluvial fan, fan delta and braided delta displayed multi-stage overlay in the vertical direction and connected each other in the horizontal direction. These alluvial fans, fan delta and braided delta formed giant sand reservoir which is the main accumulating space for gas fields (Fig.4).



Bashijiqike formation of Cretaceous, the main target layer of gas field, is the sedimentation of subfacies as fan delta foreland in the third member of strata and braided delta foreland in the first and second members of strata [12, 14].

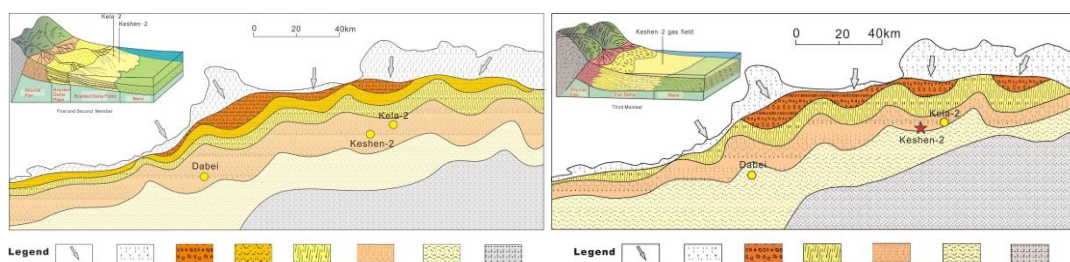


Fig. 4 Sedimentary facies of Bashijiqike formation in Keshen-2 gas field

#### 4 Characteristics of reservoir

(i) Temperature and pressure. Statistics show the reservoirs in three gas field belonging to the normal temperature system and super-high pressure gas reservoir (Tab.2). The structural compression caused the particles of rock to become more compact so that the pore space dwindled with the fluid pressure rising. The screen effect of the thick gypsiferous salt layer prevents the increasingly high pressure from discharging outwardly, thus leading to the abnormal high pressure [15-19].

Tab.2 Statistics of temperature and pressure in three gas fields

	Formation Temperature (°C)	Temperature gradient (°C/100m)	Formation Pressure (MPa)	Pressure coefficient
Kela-2	100	2.2	75	1.9-2.2
Dabe	130	2.2	90	1.5-1.7
Keshen-2	120	2.2	115	1.7-1.8

(ii) Petrology. Compared with the drilled wells in three gas fields, similar lithology in the gas pay of Cretaceous is mainly lithic-feldspar and feldspar-lithic sandstone in Dabe and Keshen-2 gas fields while lithic sandstone with more debris appeared in the Kela-2 gas field according to the thin section and mineral analysis (Fig.5).

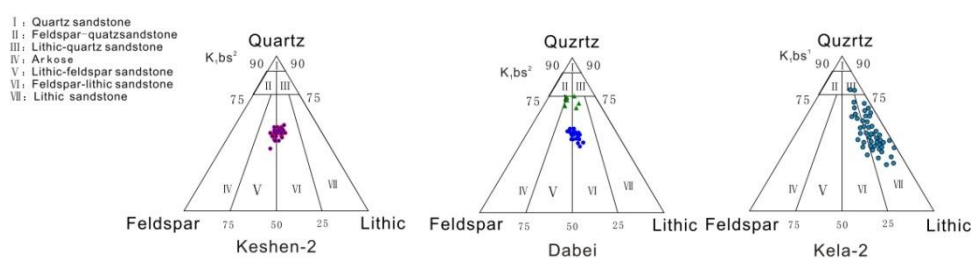


Fig. 5 Types of the reservoir sandstone in three gas fields

(iii) Physical property. The reservoir type is porous while the reservoir space is mainly residual primary intergranular pore. The secondary types are dissolution pore, intercrystal pore, micropore, structural fracture and constricted fissure<sup>[1, 20]</sup>. Different results of physical property exist in different gas field based on the research of cores and log analysis. Kela-2 gas field which characterized with relatively lower deep burial has the higher porosity and permeability compared with low porosity and permeability in Dabei and Keshen-2 gas field with deep burial (Tab.3). The final results show that the burial depth and diagenesis play an import role in the decreasing or increasing the porosity and permeability.

Tab.3 Physical property of core and log in three gas fields

Gas fields	Target Form.	Depth (m)	Core				Log			
			Por. (%)		Perm. (mD)		Por. (%)		Perm. (mD)	
			Range	mean	Range	mean	Range	mean	Range	mean
Keshen-2	K1bs	6500-7000	0.6-6.4	2.99	0.007-0.168	0.031	3.6-11.1	5.74	0.02-17.9	0.245
Dabei	K1bs	5300-7000	3.5-9	5.15	0.01-1	0.13	3.5-9	5.69	0.01-1	0.06
Kela-2	K1bs	3500-4000	8.0-20	12.6	0.1-1000	49.4	10-14	12.4	4-150	26.3

(iv) Fractures. The depth of Bashijiqike formation sandstone reservoir in Dabei-Keshen area of Kuqa depression is generally more than 5000 meters with intense compaction. The Dabei and Keshen-2 gas field as tight sand reservoirs are controlled by the fracture development which directly affects the discovery and deliverability of the natural gas<sup>[21]</sup>. Mass of research indicates that development of micro- fractures is mainly associated with depth and sandstone original texture, and the micro-fracture, to a certain extent, improves the permeability<sup>[22]</sup>. Based on the research of outcrops, cores, imaging logging and well interpretation, fractures of each gas fields were studied and the DFN (Discrete Fractures Network) model was built (Fig.6). This model can be used to predict the tendency and density of fractures.

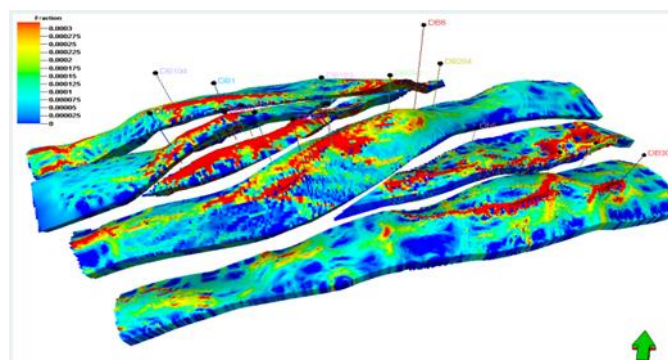


Fig.6 Discrete fractures network of Dabei gas field

(v) Inner fault. Because of the giant thickness of gypsiferous salt bed above the gas pay in KM formation and deep burial in Dabei and Keshen-2 gas field, the signals of seismic were diminished. It added the difficulty to predict the inner faults. By the latest research about Kela-2 gas field, there developed more than 200 inner faults mostly along the structural axis in the NW-SE direction in the gas reservoir (Fig. 7). The development of inner faults improve the reservoir connectivity and act as main path for overpressured fluid release and then for fast gas accumulation. At the same time, new challenge that is the coning of formation water must pay more attention. At present, the elevator of gas-water contact which is the most serious problem in Kela-2 gas field caused a series of harmful results including production reduction and dewatering. According to the preliminary analysis and analogy with Kela-2 gas field, the inner faults in Keshen-2 and Dabei gas field also developed.

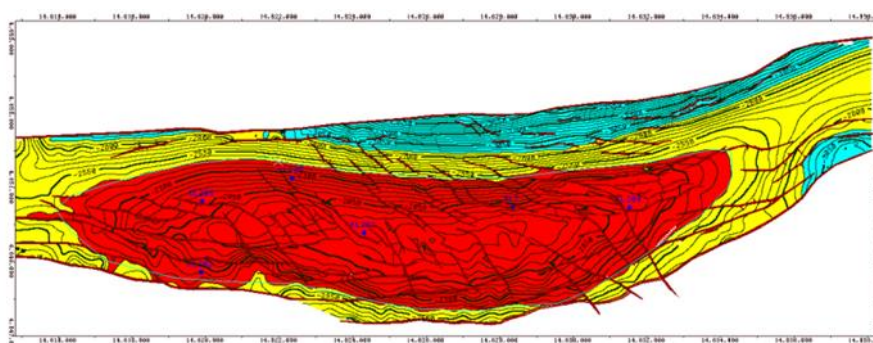


Fig.7 inner faults development in Kela-2 gas field

(vi) Characteristics of barrier and interlayer. The outcrops in the Kelasu structural belt show each muddy interlayer is less than 2m in vertical and less than 100m in horizontal (Fig.8). Statistics from logging interpretation conform to the outcrops result (Tab.4). No occurrences of effective barriers and interlayers can separate gas and water layers in these three gas fields.

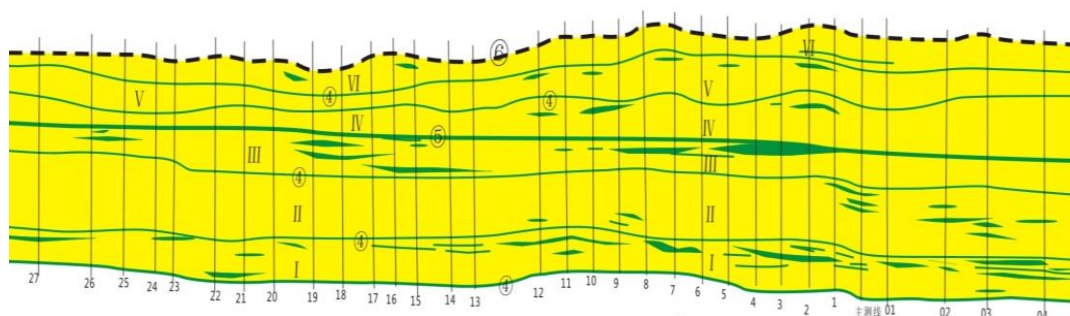


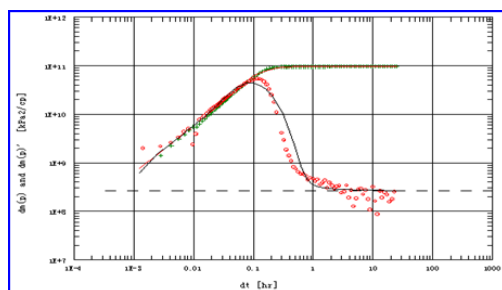
Fig.8 The distribution model of barrier and interlayer in Kelasu structural belt



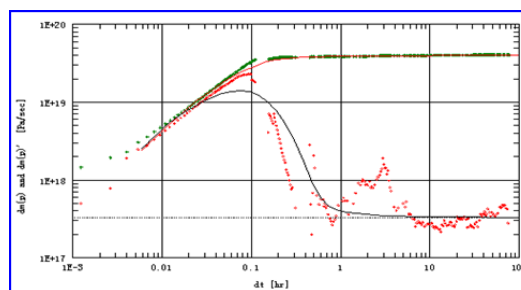
Tab.4 statistics of barrier and interlayer from log interpretation

Gas field	Thickness of strata (m)	Barriers and interlayers from log interpretation				
		Number	Total thickness	Density	Frequency	Average Thickness
Dabei	200	44	95	0.47	0.22	2.16
Keshen-2	290	78	105	0.36	0.27	1.35
Kela-2	300	34	50	0.17	0.11	1.47

(vii) Connectivity of reservoir. According to the above research, the characteristics of Keshen-2 and Dabei gas field are fracture development, high fracture density, thin thickness of interlayers and limited extending distance. From almost all the well testing data, the reservoir shows the homogeneous infinite formation and there are no evidences which show the interbedded characters (Fig.9). In the regional area, Dabei gas field has thicker interlayers than Keshen-2 gas field but the whole reservoir of Dabei gas field shows connective feature. While the fracture system in Keshen-2 gas field is more developed than Dabei gas field, it can presume that the connectivity of reservoir is better than Dabei gas field.



DB-2 well in Dabei gas field



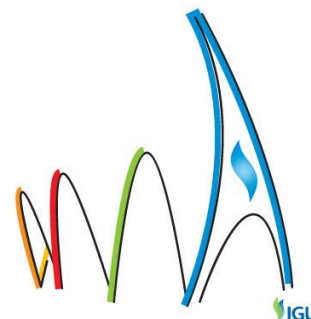
Keshen-202 well in Keshen-2 gas field

Fig.9 Well test data in Dabei and Keshen-2 gas field

## Results

Based on the analysis on these three gas fields in Kelasu Structural Belt, the geologic characteristics of giant gas accumulation are as follows: hydrocarbon distribution is mainly controlled by structural traps; physical properties was mainly confined by the burial depth; inner faults and fractures are the important controlling factor for hydrocarbon enrichment; gas distribution is characterized by the association of source rocks and capping rocks, multiple layer stacking and the entire gas-bearing beds; and hydrocarbon accumulation was controlled by faults and fractures as an important factor.

High-production industrial gas flow was obtained in Kela-2 gas field depending on the excellent quality and characters of reservoir with the proven natural gas in the place of  $2840.29 \times 10^8 \text{ m}^3$  [1]. Almost 30% production reduction at present, the main reason is the coning of formation water which displays heterogeneity in the E-W direction.



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Comparing with Kela-2 gas field, Dabei and Keshen-2 gas field which characterized with deep burial, ultra-high pressure, low porosity and permeability, complex structure are less productivity than Kela-2 gas field. The average daily gas production in individual well almost similar in these two gas fields reaches  $10\text{-}40 \times 10^4 \text{ m}^3$ . The proven reserves of the Dabei gas field is  $1 \times 10^8 \text{ m}^3$  including five fault-blocks and Keshen-2 gas field is  $1 \times 10^8 \text{ m}^3$ .

Three challenges exist in current researches of exploration and development in Kelasu structural belt as follows:

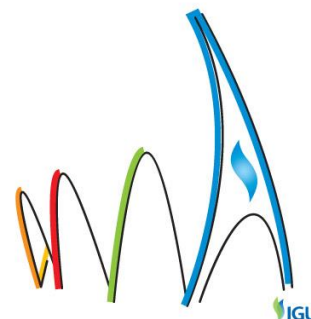
Firstly, complicated structures and giant thickness of salt belts add the difficulties in the prediction of reservoirs. At the same time, seismic accuracy affects the research of faults and time-depth relation. The distribution of fractures is also an important factor for the reservoir studies.

Second, formation water seriously influences the gas production especially in Kela-2 gas field. In Dabei and Keshen-2 gas field, gas-water contact is hard to identify that make the uncertainty of reserves and coning prevention. Average 20 cubic meters per day of formation water was produced in each water yield well of Dabei gas field.

Third, compared with the proven reserves, relative low individual well production is the huge problem in the developing progress which was caused by the properties of reservoir in Dabei and Keshen-2 gas field. Acid-curing and massive hydraulic fracturing, even horizontal well experiments in so burial depth in the future, are the valid measures to the development of deep reservoirs.

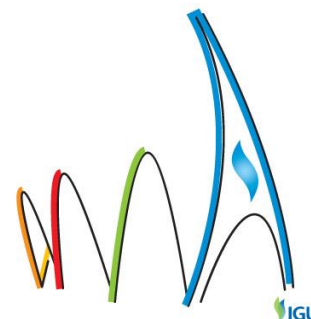
### Conclusions

Based on the comparison and study on reservoir characteristics of these three gas fields, the difference and relevant reasons of the stratigraphy, sedimentary facies, reservoir parameters, proven reserves and situation of exploration and development have been analyzed and summarized, in order to provide the reference for the study on other deep-burial gas fields in the Kelasu Structural Belt and effective experience for further exploration and development in the Kelasu Structural Belt and Kuqa Depression.



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